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DEPARTMENT OF DEFENCE

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

AERONAUTICAL RESEARCH LABORATORY

MELBOURNE, VICTORIA

Aero Propulsion Technical Memorandum 446

DEVELOPMENT AND INSTALLATION OF AN INSTRUMENTATION PACKAGE FOR GE F404 INVESTIGATIVE TESTING (U)

by

D.K. Streatfeild

Approved for Public Release.

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DEVELOPMENT AND INSTALLATION OF AN INSTRUMENTATION PACKAGE FOR GE F404 INVESTIGATIVE TESTING (U)

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SUMMARY

The development and installation of an Instrumentation Package for GE F404 Investigative Testing is described. The package is used in conjunction with the ARL Mobile (Transient) Data Acquisition System (MODAS) and can be used on the F404 engine at both Fixed or Mobile Engine Test locations - AGAETF or METS.

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MELBOURNE

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1. INTRODUCTION

Prior to embarking on Phase 2 of a scheduled investigative engine test program on the RAAF's F404 Engine S/No 392002, a requirement was established for the development, and installation on the F404 engine, of an instrumentation package capable of measuring engine steady state and transient engine performance. The instrumentation package is used in conjunction with the ARL Mobile (Transient) Data Acquisition System MODAS, Reference 1. This memorandum details the development and installation of the instrumentation package from the mechanical, and to a lesser extent the electrical, aspects. The instrumentation package can be used in the engine test cell (AGAETF at HdeH) or can be used in the field - RAAF Base - in conjunction with a mobile engine test stand (METS).

2. EQUIPMENT SELECTION

The selection of equipment/instrumentation was based on the engine measureands to be obtained during the performance testing; Appendix A details these requirements. In a number of cases it necessitated manufacturing and purchasing items of equipment to achieve the required objectives. Complicating the task were the extremes of temperatures and pressures required to be measured in the F404 engine. The temperatures ranged from ambient to approximately 500^{O}C whilst the pressures ranged from static (ambient) to approaching 500 psi. Type 316 stainless steel was used where possible, however brass was used at locations around the inlet in areas of low temperature. Appendix B details the equipment requirements. A pictorial reference to the parts manufactured in house is given in Appendix C.

3. ENGINE GENERAL

The following comments on engine handling and location of equipment on the engine should be noted prior to installing instrumentation on an F404.

3.1 Cautions

a. A large majority of F404 components are manufactured from titanium alloy. Carbon pencil lines as reference points are forbidden as the carbon reacts with titanium by carborizing the surface and creating oxidization. If the carbon

pencil has a high sulphur content, it can also cause surface corrosion, leading to intergranular corrosion and subsequent component failure.

b. The F404 Engine like all gas turbine engines is susceptible to Foreign Object Damage (FOD). Extreme care must be exercised when working on the engine. Misplaced nuts, bolts, washers, spanners etc, must be located before engine testing is commenced.

c. Prior to commencing work on the engine always ensure the engine is mounted securely in its work platform and all safety locks engaged.

d. With the exception of the Fan Exit-Static Pressure and the Low Pressure Turbine sensing adaptors, all other ARL manufactured pressure tappings have a **built in restrictor**. The restrictor side of the connection MUST be connected to the Test Cell side of the line and NOT to the ARL side.

e. Three types of PVC tubing are used by ARL for sensor lines. These are:

(i) Black - Intake Bellmouth area.
(ii) Opaque - Low Pressure/Low Temperature PVC tubing, and
(iii) White - High Pressure/High Temperature Teflon tubing.

3.2 Notes

a. All angular position locations referred to are as viewed from the rear of the engine looking forward and all longitudinal positions are from the front of the engine rearwards.

b. All instrumentation components are mounted on the starboard side of the engine between the 12 and 5 o'clock position. This allows for constant monitoring of the instrumentation package via the test cell video camera, whilst the engine is operating. Refer Figure 1 for details.

c. All engine hardware tensions, unless otherwise stated, are standard tensions. Refer Appendix D.

d. Station numbering is given in Appendix E.

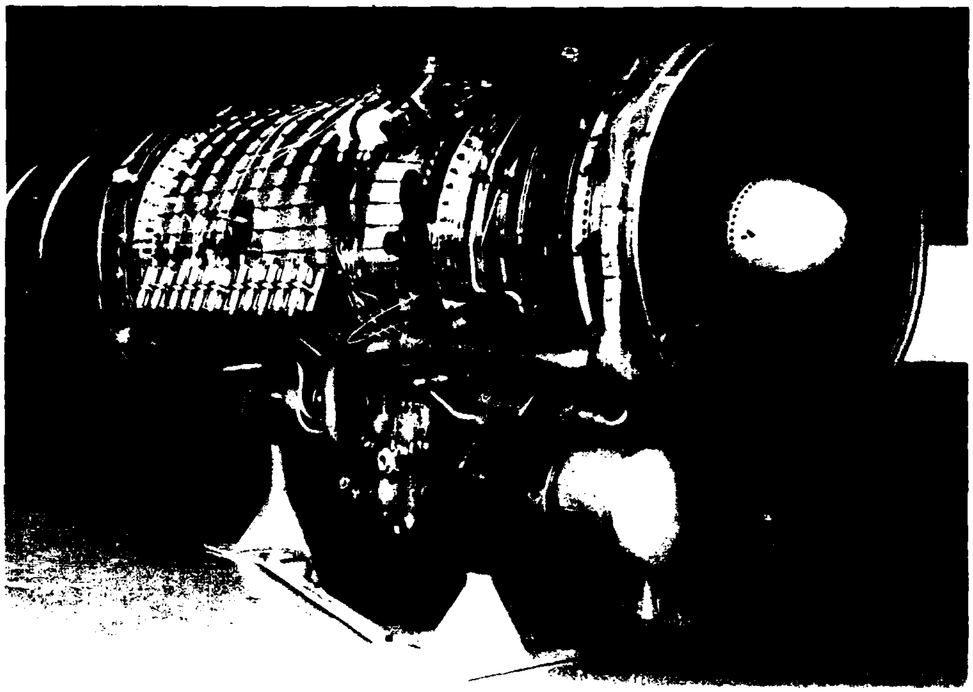


FIGURE 1

4. TEMPERATURE SIGNAL CONDITIONING SYSTEM

The temperature signals are transmitted in millivolt form, through Type E thermocouple wire, to an Analog Devices Inc. 3B-Series Signal Conditioning System. Signals from the thermocouples are converted from millivolts to volts by temperature transmitters for input to the ARL Data Acquisition System. The following F404 temperature signals are connected via the 3B-Series System:

a. Bellmouth Inlet Screen - 1 off

b. Fan Exit - 5 off

c. High Pressure Compressor Outlet - 4 off

4.1 Mounting: The Temperature Signal Conditioning Box is mounted on the starboard side of the engine adaptor frame aft of the frame lead weights. Refer Figures 2 and 3 for details.

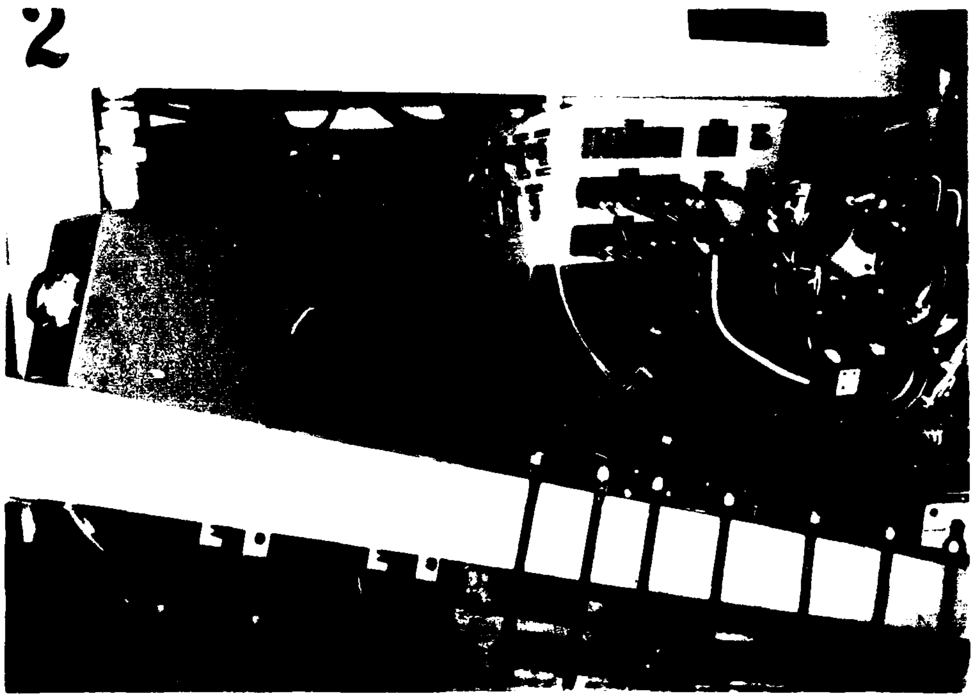


FIGURE 2

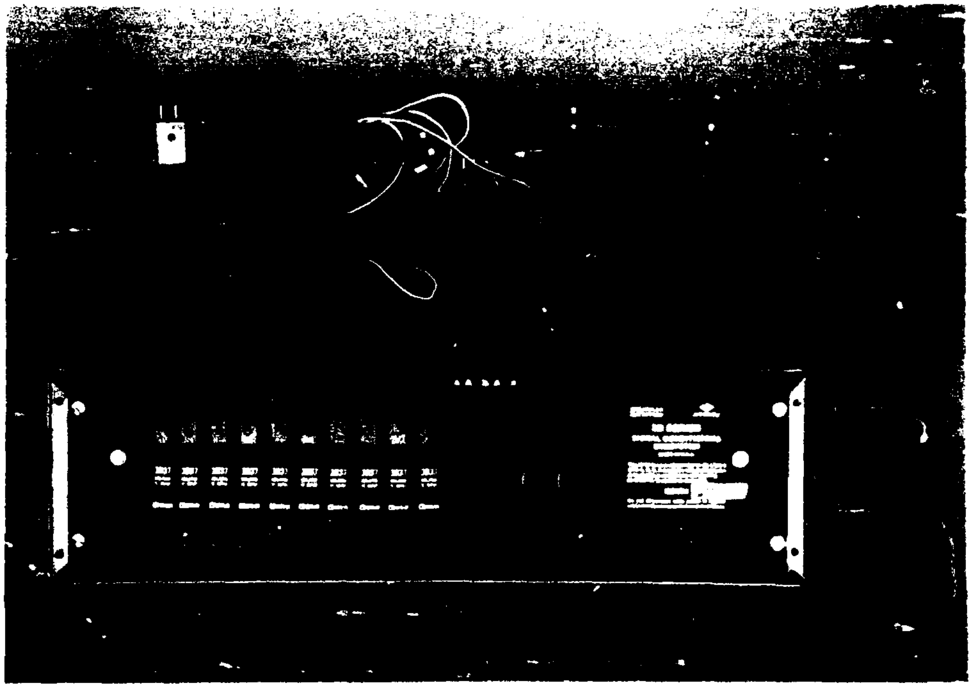


FIGURE 3

5. INSTRUMENTATION INSTALLATION - ENGINE

5.1 Intake Bellmouth : The Intake Total/Static Pressure Rake used by ARL is located on the Bellmouth at the 1 o'clock position. The rake consists of six static and six total pressure probes, both of which are clearly marked. To install the ARL transducers:

a. Remove the lower three "securing" nuts from the probe assembly and install the transducer mounting bracket complete with two 22" to 32" Hg absolute Rosemount pressure transducers.

b. Disconnect the 'E' Total Pressure line from the 'quick disconnect' and install the branch line. Reconnect the cell sensor line.

c. Disconnect the 'Bellmouth Wall Static' line at the 'T' Junction (just forward of the total pressure probe) and install the ARL adaptor. Reconnect the cell sensor line.

Caution: Ensure Brass Insert (Restrictor) is located in cell PVC sensor line.

d. Connect ARL Transducers to tapping points via PVC tubing and Swagelok quick disconnects. Refer Figure 4 for details.

FIGURE 4

5.2 Intake Bellmouth Screen - Total Temperature: A temperature signal was taken from one of the 24 existing Total Temperature sensors on the Bellmouth Screen. The selection of a suitable central sensor was made in conjunction with the graphic display from the F404 Test Cell Computer System. An electrical connection is made on the forward thermocouple bulkhead mounted on the engine adaptor using "siamesed" Type E Thermocouple connectors allowing the Analog Devices Inc. 3B-Series Signal Conditioning System to parallel the normal Test Cell sensing equioment, see Section 4.

5.3 Fan Variable Guide Vanes - FVGV: The FVGV position indicator is mounted on the unison ring lever at the 1.30 position on the Fan Inlet Casing. To install FVGV Potentiometer:

a. Identify the nut securing the lever to the Variable Guide Vane. De-tab the tab washer and remove the nut. Remove and discard the tab washer. Remove the two bolts immediately adjacent to the unison lever that align with the bracket holes.

b. Install and tension the coupling adaptor to the threaded portion of the variable guide vane shaft. Insert the rotary potentiometer shaft into the coupling adaptor, align bracket holes and install mounting bolts. Tension bolts to specified torque. Tension the adaptor-to-shaft lock bolt and nut. Refer Figure 5 for details.

Caution: Ensure the flat section of the shaft is adjacent the lock screw. This automatically sets the potentiometer to a known value.

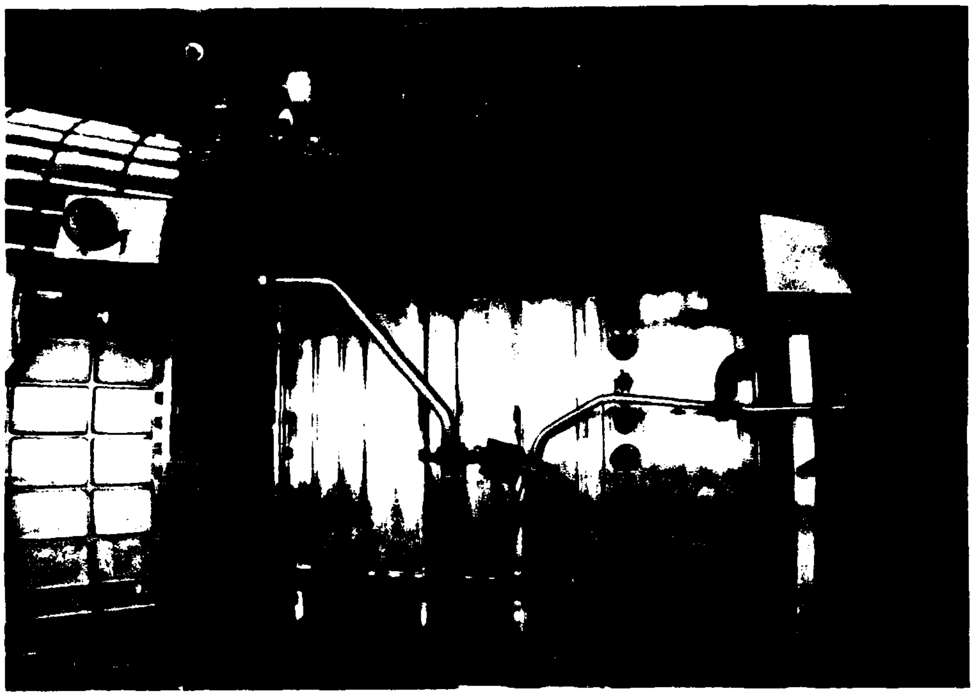


FIGURE 5

5.4 Compressor Variable Guide Vanes - CVGV: The CVGV position indicator is mounted to the starboard actuating ram at the 1.30 position on the rear of the Low (Fan) Speed Compressor Casing. To install CVGV Potentiometer:

a. Identify the nut securing the lever to the Variable Guide Vane Shaft. Remove the nut. Leave the locking wave washer in place. Remove the two bolts immediately adjacent to the actuating lever that align with the bracket holes.

b. Proceed as per paragraphs 5.3b. Refer Figure 5 for details.

5.5 Fan Exit - Static Pressure: A tapping for Fan Exit Static Pressure was obtained by utilizing the Boroscope Inspection port, located just below the starboard forward engine mount. To install ARL manufactured plug insert with a static pressure hole:

a. Remove the boroscope blanking plug and insert the ARL plug.

b. Remove the two bolts immediately adjacent to and to the right of the plug and mount the transducer support bracket complete with 0-100 psia transducer.

c. Connect the ARL transducer to tapping point via PVC tubing and Swagelok quick disconnect. Refer Figure 6 for details.

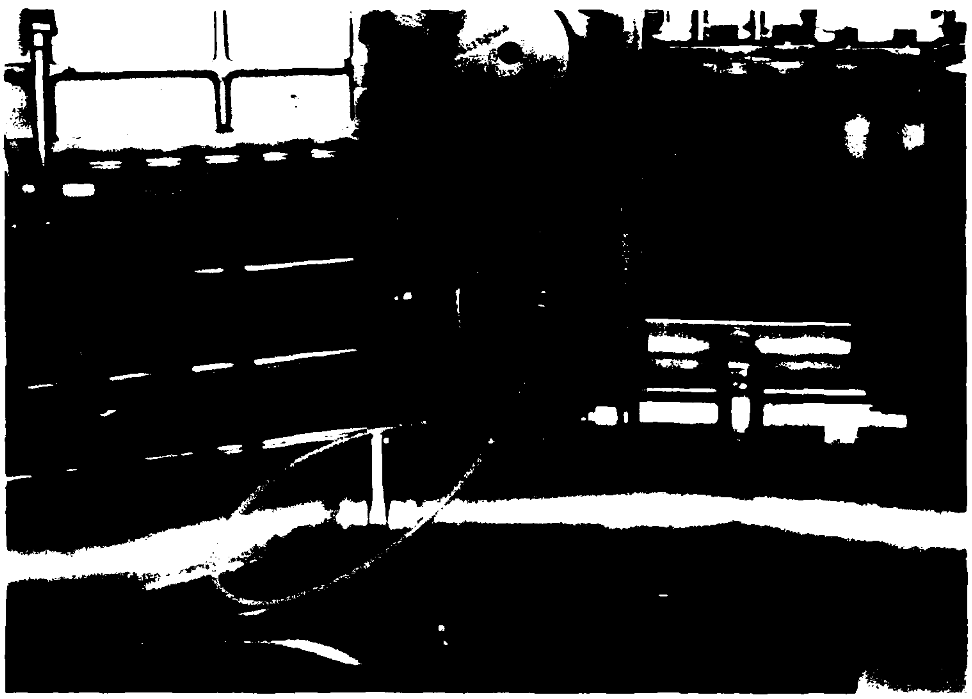


FIGURE 6

5.6 Fan Exit - Total Pressure: Identify the F404 (AGAETF) Total Pressure Probe located at the 12.30 position on the Fan Exit Case. To install ARL measuring equipment:

a. Disconnect the five quick disconnect tapping points.

b. Connect the five ARL tee piece tapping points and reconnect the cell sensor lines to the in-line quick disconnects. Refer Figure 7 for details.

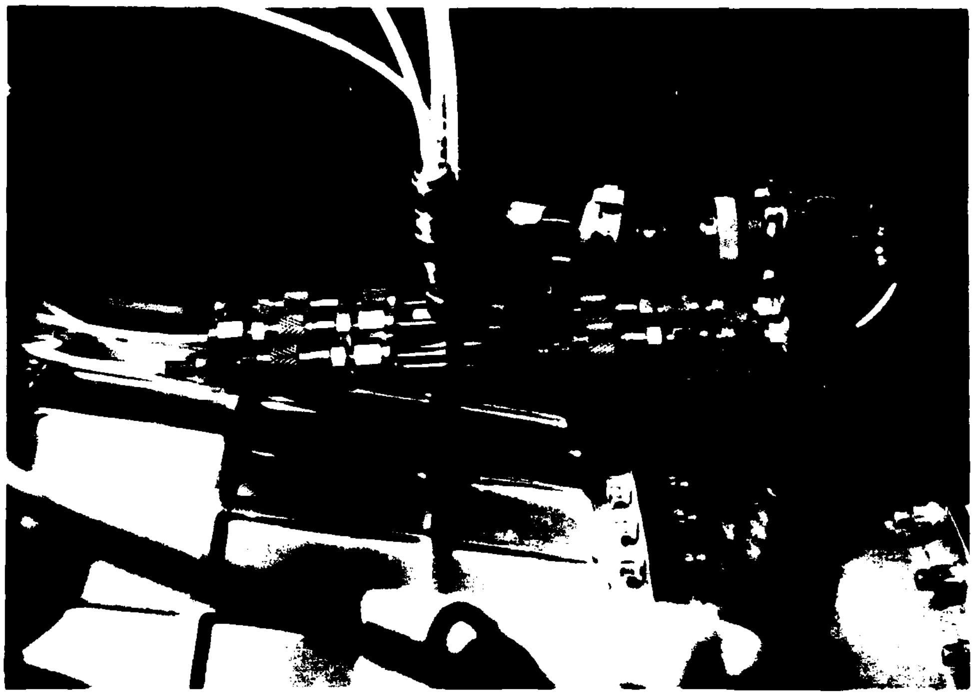


FIGURE 7

c. Locate the Fan Duct Outer casing split line, 3 o'clock position, and remove matching bolts, thereby allowing transducer mounting bracket to be

installed. Install mounting bracket to engine, tension nuts and install five 0 - 150 psia transducers.

d. Connect the five transducers to the five tee pieces via PVC tubing and Swagelok quick disconnects. Refer Figure 8 for details.

FIGURE 8

5.7 Fan Exit - Temperature: The F404 (AGAETF) Fan Exit Temperature Probe is integral with the Fan Exit Total Pressure Probe. A millivolt (Temperature) signal is transmitted by siamesed Type E Thermocouple connectors to the Analog Devices Inc. 3B-Series Signal Conditioning System. Connect as follows:

a. Disconnect the five-thermocouple-probe wiring harness from the Thrust Frame Temperature Junction Box.

b. Insert the five ARL siamesed thermocouple lines into the junction box and connect the five-probe-harness (from engine), to the ARL thermocouple harness. Refer Figure 9 for details.

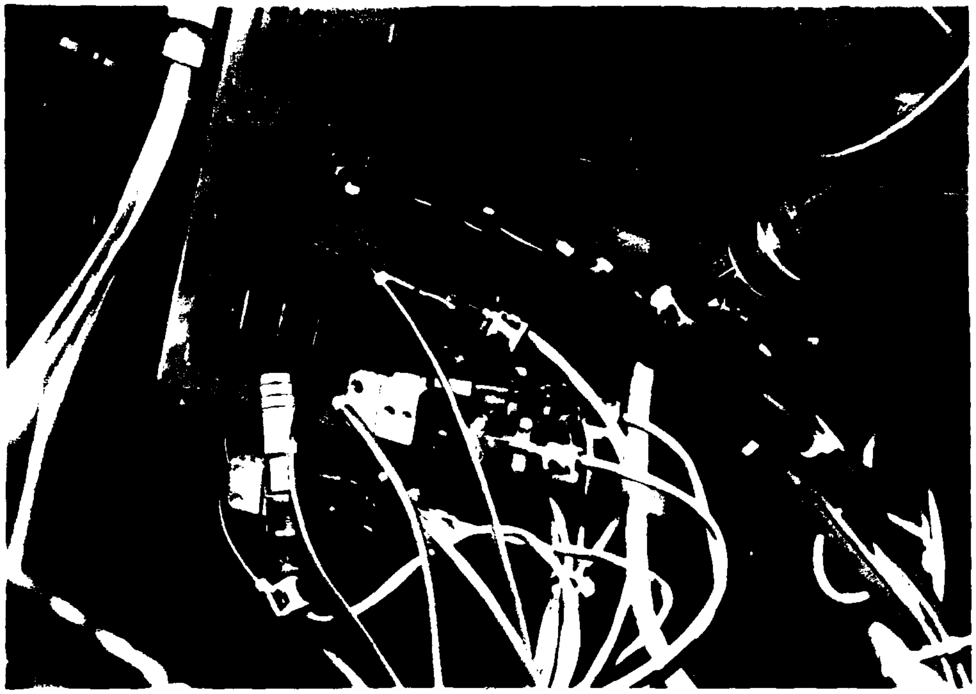


FIGURE 9

5.8 High Pressure Compressor - Total Prrssure: A standard General Electric (GE) High Pressure (Calibration) Compressor Exit Probe P/No 17A125-647 with four pressure and four temperature tapping points was used. For the purpose of this test only two pressure tappings (Ports C & D) were used to monitor total pressure. Port A

was blanked off, due to limitations on the number of data acquisition channels available, whilst Port B although also measuring pressure, (refer para 5.12 for details) was used to control another test function. To install:

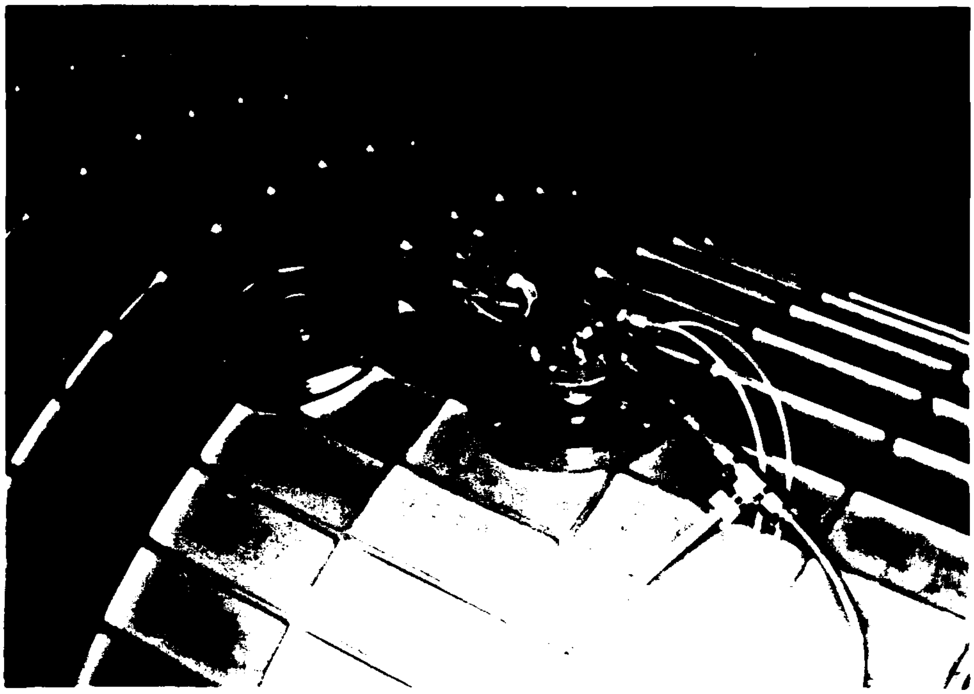


FIGURE 10

a. Remove the forward boroscope inspection blanking plug located at the 12 o'clock position.

CAUTION: THIS PRESSURE/TEMPERATURE PROBE IS EXTREMELY FRAGILE AND WILL BREAK AT THE THREAD AREA IF ALL INSTRUCTIONS ARE NOT FOLLOWED.

Note: Prior to inserting Pressure/Temperature probe into engine, apply a liberal amount of anti-seize compound to the threaded area.

b. Carefully insert (so as not to damage the pick up points) the probe into the engine. Screw the probe by hand until it bottoms.

c. Place a torque wrench, with a crow foot adaptor, on the wrench flats under the rake pad. **Torque to 50 inch/lbs maximum.**

d. To align the probe, remove or loosen the two locking bolts on the top side of the probe pad. Rotate the probe so that the arrows on the probe pad point forward.

e. Reinstall the bolts, if necessary, and appropriately tension the bolts. Refer Figure 10 for details.

5.9 High Pressure Compressor - Total Temperature: Four total temperature tappings are taken utilizing the standard G.E. probe as described in para 5.8. The millivolt (temperature) signals are taken via Type E thermocouple cables to the Analog Devices Inc. 3B-Series Signal Conditioning System. To install:

a. Connect the thermocouple wiring harness from the ARL Signal Conditioning System directly to the temperature pick-up probe: Refer Figure 11 for details.

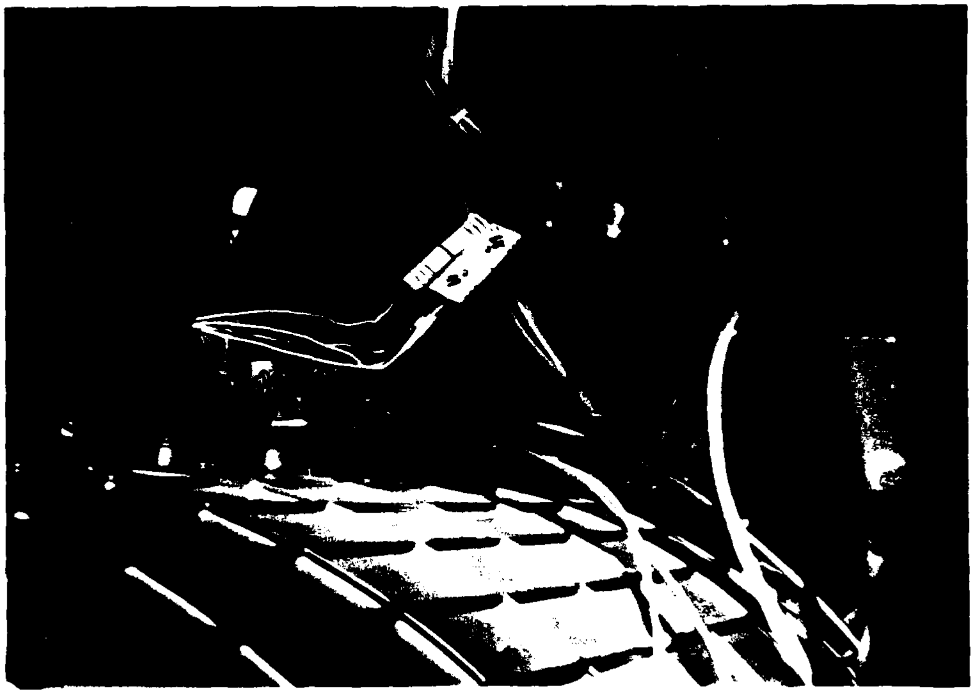


FIGURE 11

5.10 <u>High Pressure Compressor - Static Pressure</u>: This is a standard F404 test cell instrumentation point. Remove the boroscope inspection blank located at the 3 o'clock mid engine position. To install the ARL probe:

<u>Caution</u>: Prior to inserting the Static Pressure probe into the engine apply a liberal amount of anti-seize compound to the threaded area.

a. Insert the probe into the engine and hand tighten till bottomed. Tension probe to 50-80 inch/lbs.

b. Connect and tension the Test Cell pressure sensor line.

c. Locate the Fan Duct Outer casing split line at the 3 o'clock position and remove matching bolts, thereby allowing transducer mounting bracket to be installed. Install mounting bracket to engine, tension nuts and install four 0-500 psia transducers.

d. Connect the transducers in the following sequence;

(1) Connect Probe Port B to Transducer # 4 ($1/4$" S.S. Tube).

(2) High Pressure Compressor-Static Pressure to Transducer # 3, and

(3) Probe Ports C and D to Transducer # 2 and # 1 respectively. Refer Figure 12 for details.

FIGURE 12

5.11 Low Pressure Turbine - Outlet Total Pressure: This pressure is obtained by tapping into the existing low pressure turbine outlet total pressure transducer line at the point where it exits from the turbine casing by releasing the support bracket, flexing the transducer line, and installing the ARL manufactured "S" bend fitted with a Tee section. To install:

a. Mount the transducer support bracket on the Fan Outer Duct Casing Split line. Install the 0 - 50 psia transducer and connect the transducer to the sensor point via Teflon tubing and Swagelok quick disconnect. Refer Figure 13 for details.

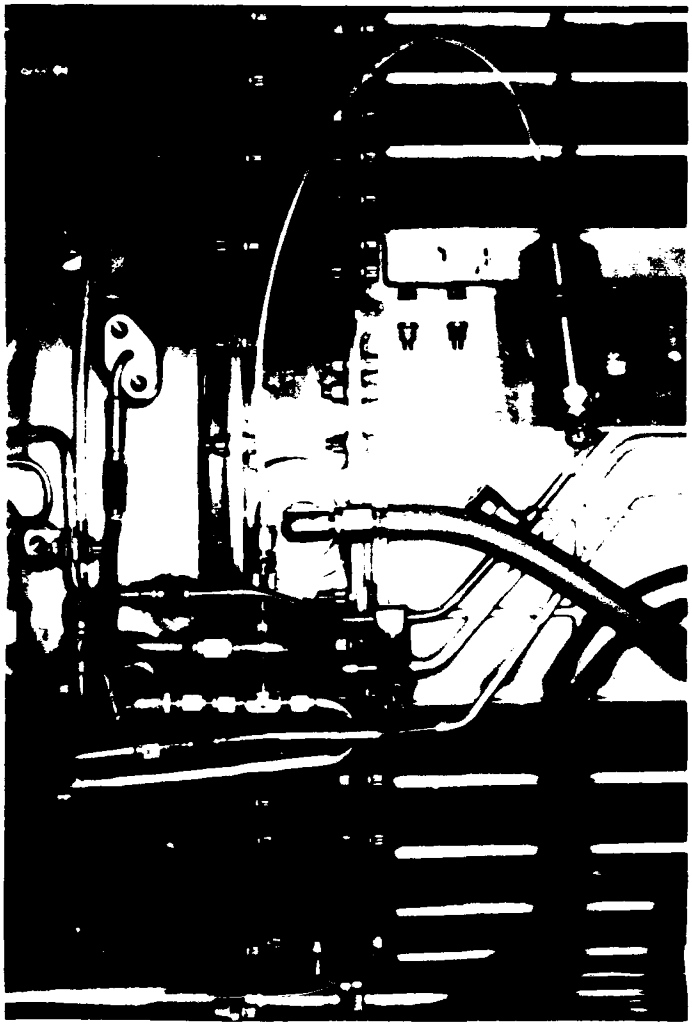


FIGURE 13

5.12 High Pressure Compressor - Total Pressure to Static Pressure Superimposition: A requirement existed to generate an artificial fault to the engine Fuel control Unit (FCU) system. This was attempted by tapping into the High Pressure Compressor Total Pressure probe, to enable High Pressure air to be transferred via a Tee piece and stainless steel tubing to the p_3 (static) line to the FCU. The Static Pressure line to the FCU was broken into at the engine transducer point (4 o'clock position) aft of the engine oil tank. An isolating valve was installed in the line to separate physically the two pressures. Refer Figure 14 and 15 for details. To install:

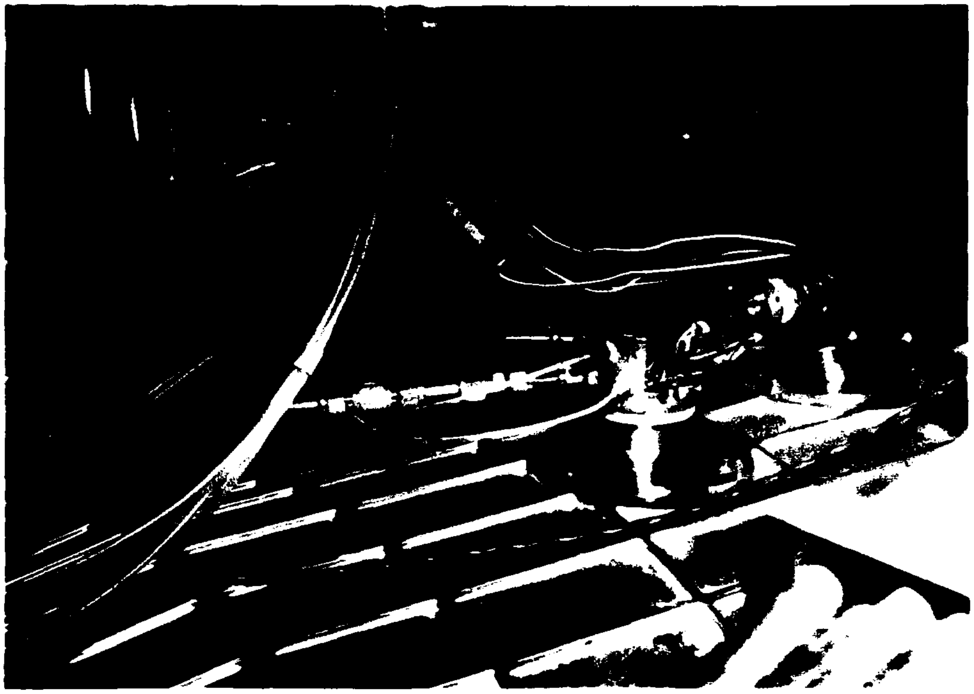


FIGURE 14

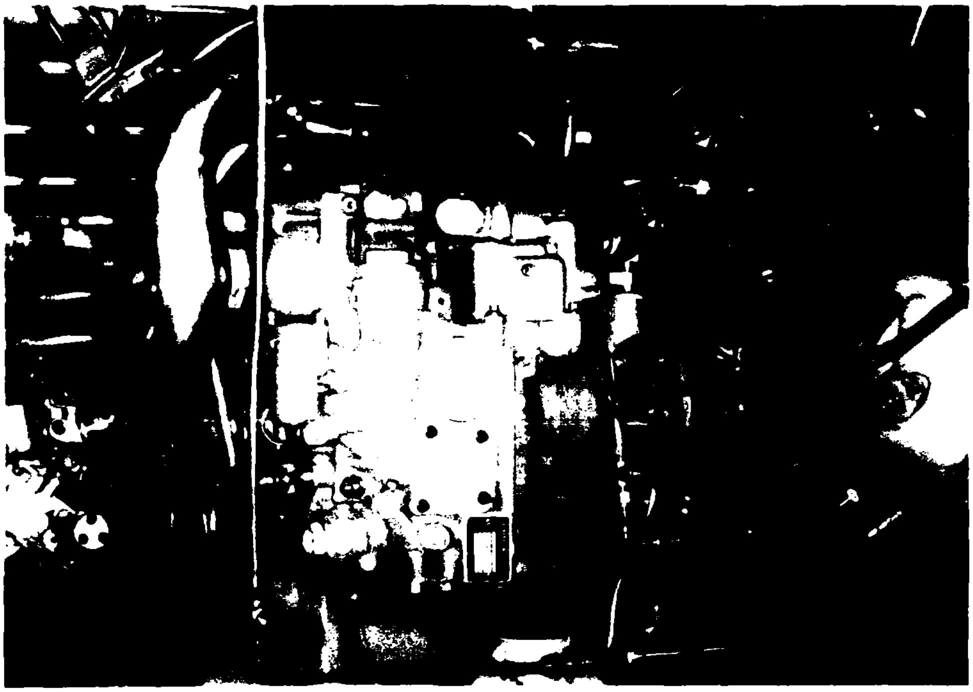


FIGURE 15

a. Electrically disconnect the P_3 engine IECMS transducer. Disconnect the Engine P3 sensor line and remove the transducer from its mounting position.

b. Install the ARL manufactured bracket to the transducer mounting position and install the original engine transducer plus one ARL 0-500 psia transducer to the bracket. Electrically reconnect the original engine IECMS transducer.

c. Connect the ARL manufactured plumbing to the two transducers. Connect the isolating valve and associated plumbing to the transducer plumbing and to Port B of the High Pressure Compressor - Total Pressure probe. (Figure 14 and 15

refers). Connect the stainless steel tubing from the Tee piece to transducer # 4 (Figure 12 refers).

5.13 Additional Parameters: An additional nine measuring parameters completed the instrumentation package. Six of the instrumentation points were to be coupled directly to the engine. However due to the non availability of unique IECMS E1 and E2 Electrical Plugs, and the difficulty of being able to connect to the Engine Power Lever alternative arrangements for obtaining these parameters were required.

5.14 The following is a listing of the nine parameters. For their location refer to Reference 2.

a. Barometric Pressure (P_{bar})
b. Compressor Inlet-Total Temperature
c. Low Pressure Turbine-Outlet Total Temperature
d. Exhaust Nozzle Area
e. Fan Rotor Speed N_1
f. Compressor Rotor Speed N_2
g. Power Lever Angle (PLA)
h. Engine Thrust
i. Fuel Flow

Notes
(1)Items b, c, d, e originally required from IECMS E1 Plug.
(2)Item f originally required from IECMS E2 Plug.
(3)Item g. originally required from ARL Designed and Mounted rotary potentiometer.

6. DISCUSSION

6.1 Three areas of concern arose during the testing of the RAAF's F404 Engine S/N 392002 in the Australian Government Aero Engine Test Facility at Hawker de Havilland Melbourne during the test period. These were:

a. Low Pressure Turbine Outlet - Total Pressure (P_{56}). The engine repeatably failed the DAPPER P56 performance check. It would appear that a leak developed within the ARL equipment. However it is yet to be ascertained at what stage of the test programme the problem occurred. The leak was traced to the Teflon sensor line from the tapping point to the transducer. This was most probably due to the Teflon tubing shrinking from its fittings due to the high temperatures experienced.

b. High Pressure Compressor - Total Pressure to Static Pressure Superimposition $P_3 = p_3$. With the engine operating in a steady state condition at a Power Lever Angle of 80 degrees the isolating valve was opened, thereby superimposing Total Pressure (P_3) from the High Pressure Compressor into the Static Pressure (p_3) Fuel Control Unit sensor line and hence Fuel Control Unit pressure bellows. No change was observed in the engine operating condition, there was no change in engine RPM nor was there any change in P_3 (static) at the FCU. It is considered that insufficient Air Mass Flow was obtained from the Total Pressure, due it is believed, to the small pick up points in the GE Calibration Probe being used.

c. Fuel Flow. The Fuel Flow signal received from the AGAETF Quantum Dynamics Turbine Flow Meter was too **low** (level and frequency) at low engine speed. The flowmeter is designed for engines up to 40000 pounds of thrust. An alternative system was utilized, whereby an analogue version of the signal from the engine mounted fuel flow (pulse rate) meter was input to the ARL Data Acquisition System.

d. T_1 Offset. The Test Cell performance checks of T_1 read low throughout the testing phase due, most probably, to the ARL instrumentation system loading the circuit.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 In general all the Mechanical and Electrical equipment fitted to the test engine performed as anticipated without breakdown. The equipment was easy to install and totally accessible during the testing period.

7.2 Dependent on future testing requirements for both the RAAF and ARL, it is recommended that:

a. All high pressure/high temperature sensor lines should be changed from Teflon tubing to 1/8" dia Stainless Steel tubing, thereby greatly reducing the possibility of leakage.

b. That ARL investigate the design aspects of an immersion probe to tap off a greater supply of Compressor Air Mass Flow at a pressure higher than the compressor outlet static pressure p_3 signal to the FCU for fault generation purposes.

c. That ARL install a more suitable turbine flowmeter in the spare AGAETF engine fuel supply system to allow a more accurate means of measuring engine Fuel Flow during ARL tests.

d. That ARL modify the T_1 circuit to prevent it offsetting the AGAETF signal.

e. Purchase of IECMS E1 and E2 plugs be expedited.

REFERENCES

1. A.S. VIVIAN, D.E. GLENNY. MODAS - A Mobile Data Acquisition System for Investigatory Engine Testing - Its Capabilities and Application. ARL AERO PROP TECH MEMO in preparation.

2. ARL S398/23 (69) F404 ARL INSTRUMENTATION. ARL LETTER TO HdeH. 16 April 1987.

APPENDICES

A. Engine Measureands - Investigative Testing G.E. F404 Instrumentation Package.

B. Equipment Requirements - Investigative Testing G.E. F404 Instrumentation Package.

C. Pictorial Reference - Investigative Testing G.E. F404 Instrumentation Package.

D. Standard Engine Hardware Tension Specifications.

E. F404 Station Location Chart.

APPENDIX A

ENGINE MEASUREANDS - INVESTIGATIVE TESTING
G.E. F404 INSTRUMENTATION PACKGAGE

PRESSURES

Intake Bellmouth	:	1 x Total Pressure
		1 x Static Wall Pressure
Fan Exit	:	5 x Total Pressure
		1 x Static Pressure
H.P. Compressor Outlet	:	4 x Total Pressure
		1 x Static Pressure
L.P. Turbine Outlet	:	1 x Total Pressure

TEMPERATURES

Intake Bellmouth	:	1 x Temperature Tapping
Fan Exit	:	5 x Temperature Tappings
HP Compressor Outlet	:	4 x Temperature Tappings

OTHERS

Fan Variable Guide Vanes	:	1 x Angular Movement	
Compressor Variable Guide Vanes	:	1 x Angular Movement	
Barometric Pressure	:	1 x)	
Compressor Inlet Total Temp	:	1 x)	
Low Pressure Turbine - Outlet		)	
Total Temperature	:	1 x)	
Exhaust Nozzle Area	:	1 x)	AGAETF
Fan Rotor Speed N_1	:	1 x)	SUPPLIED
Compressor Rotor Speed N_2	:	1 x)	
Power Lever Angle (PLA)	:	1 x)	
Engine Thrust	:	1 x)	
Fuel Flow	:	1 x)	

APPENDIX B

EQUIPMENT REQUIREMENTS - INVESTIGATIVE TESTING

G.E. F404 INSTRUMENTATION PACKAGE

GENERAL

1/4"	O.D. Stainless Steel Tubing
1/8"	O.D. Stainless Steel Tubing
1/16"	O.D. Stainless Steel Tubing
3/8"	O.D. Brass Rod
5/8"	HEX Brass
7/8"	HEX Brass
1/8"	O.D. Low Pressure/Low Temperature Flexible Nylon Tubing
1/8"	O.D. High Pressure/High Temperature Flexible Teflon Tubing

SWAGELOK STAINLESS STEEL 316 FITTINGS

17 x SS-QM2-B-200	QM Quick Connect Body
17 x SS-QM2-S-200	QM Quick Connect Stem
4 x SS-400-A-4ANF	Swaglok to AN Adaptor
1 x SS-401-PC-2	Reducing Port Connector
4 x SS-400-3	Union Tee
3 x SS-400-6-4AN	Swagelok to AN Connector
1 x SS-400-6-2	Reducing Union
1 x SS-1RS4	Valve
14 x SS-402-1	Nut 1/4" Tube O.D.
2 x NY-200 Sets -10	Ferrule Sets

PRESSURE TRANSDUCERS

3 x Rosemount	22" to 32" Hg absolute
1 x Rosemount	0 - 50 psia
1 x Rosemount	0 - 100 psia
5 x Rosemount	0 - 150 psia
5 x Rosemount	0 - 500 psia

ROTARY POTENTIOMETER

2 x 100K Rotary Potentiometer

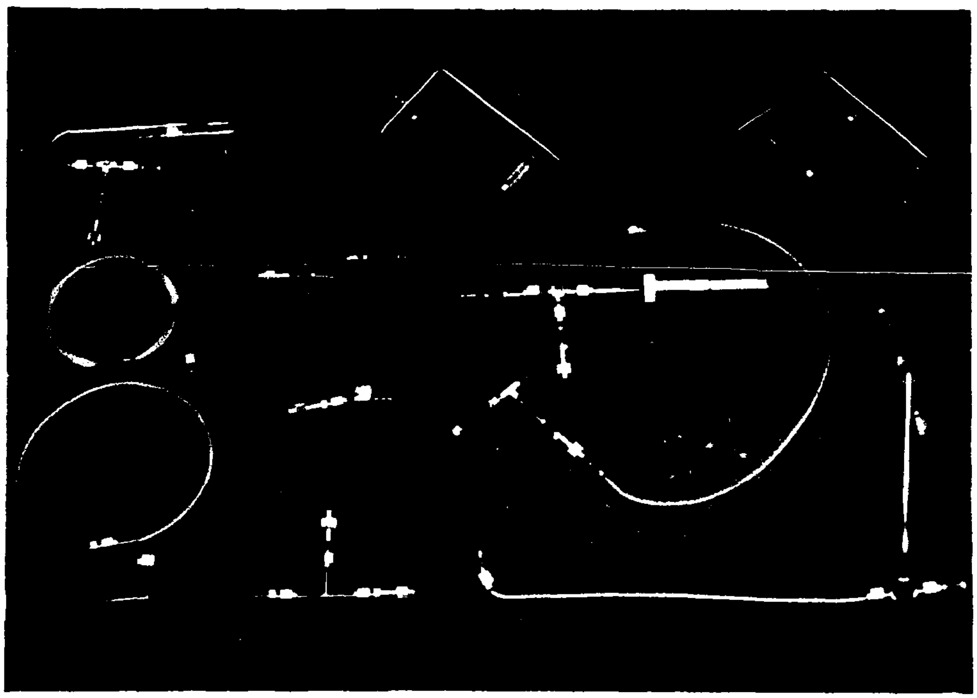
TEMPERATURE CONDITIONER

10 X (Analog Devices Inc.) 3B-37s configured to specific ranges.

APPENDIX C

PICTORIAL REFERENCE - INVESTIGATIVE TESTING

G.E. F404 INSTRUMENTATION PACKAGE



STANDARD ENGINE HARDWARE TENSION SPECIFICATIONS

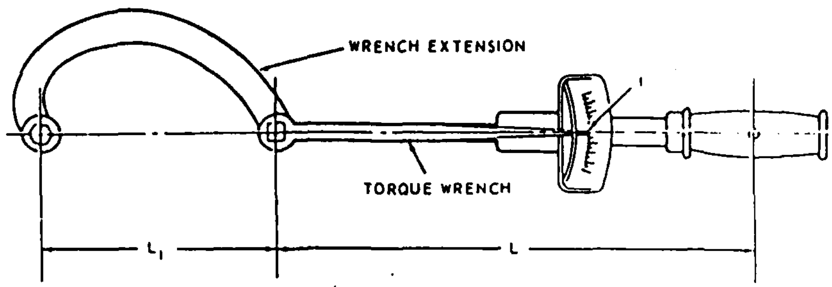
Standard Steel Screws, Bolts and Nuts

Thread Size	Torque Value lbf in	
	Slotted-head Screws	Hexagon-head Bolts and Nuts
2-56	2 to 3	
3-48	3 to 4	
4-40	5 to 6	
5-40	6 to 7	
6-32	7 to 9	
8-32	10 to 12	
10-32	18 to 20	40 to 45
7/32-24	22 to 25	65 to 70
1/4-28	30 to 35	70 to 95
5/16-24	40 to 45	120 to 165
3/8-24	55 to 60	250 to 325
7/16-20	80 to 90	400 to 475
1/2-20 or -13	100 to 110	500 to 700
9/16-18		750 to 1000
5/8-18		1000 to 1400

Jam Nuts, Bolts and Fittings used with Gaskets

Tubing OD inches	Thread Size	Torque Value lbf in*
1/8	5/16-24	45 to 50
3/16	3/8-24	60 to 70
1/4	7/16-20	90 to 100
5/16	1/2-20	120 to 130
3/8	9/16-18	150 to 160
1/2	3/4-16	275 to 300
5/8	7/8-14	375 to 400
3/4	1-1/16-12	550 to 600
1	1-5/16-12	800 to 900
1-1/8	1-5/8-12	900 to 1000
1-1/2	1-7/8-12	900 to 1000

*for use with nuts PN MS9099, MS9100, MS9200, MS9201, plug PN MS9015, union PN AN815 and bolts - universal (banjo) fitting PN AN774, AN775



$$I = \frac{RL}{L + L_1}$$

I = Indicated torque on wrench.

R = Required torque of bolt or nut.

L = Length of torque wrench (wrench head to midpoint of handle) in inches.

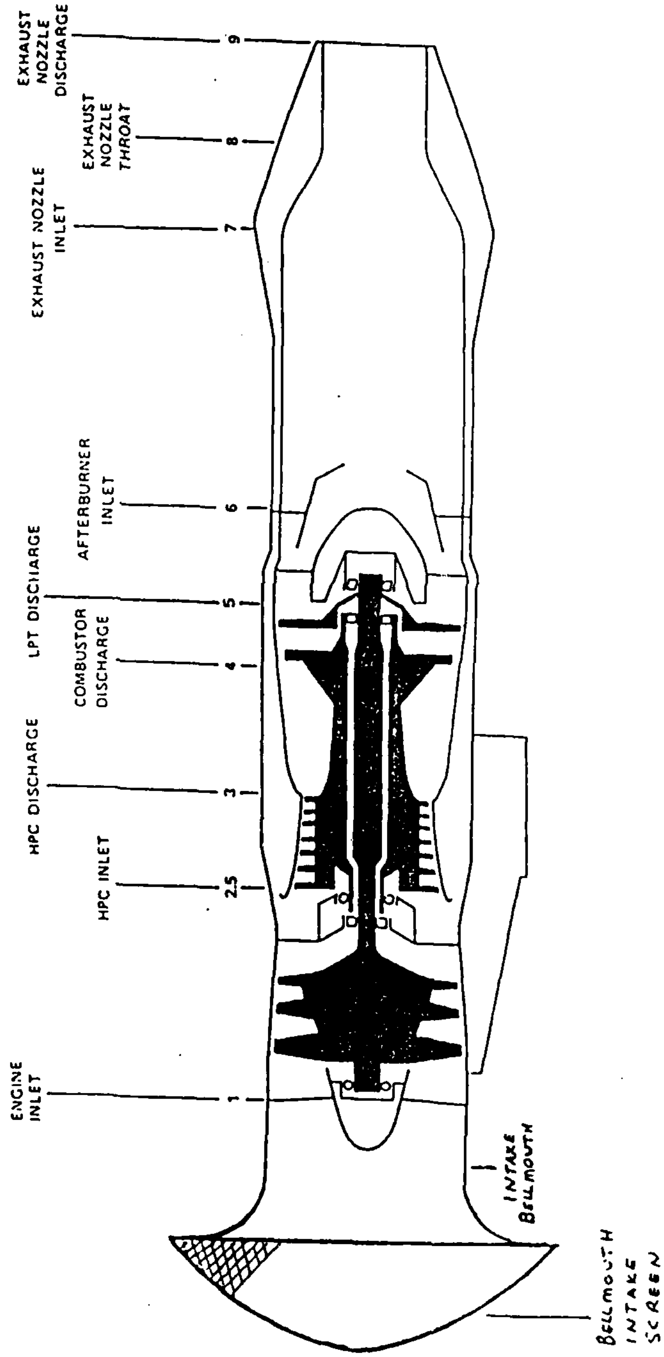
L_1 = Length of extension or adapter (centre to centre distance) in inches.

Figure :D.1 Application of Torque Wrench Extension Formula

Table :D.1 Recommended Torque Wrench Sizes

Required Torque	Torque Wrench
0 to 25 lbf in	30 lbf in
25 to 140 lbf in	150 lbf in
140 to 550 lbf in	600 lbf in
30 to 140 lbf ft	150 lbf ft
140 to 240 lbf ft	250 lbf ft
240 to 1000 lbf ft	1000 lbf ft

F404 STATION LOCATION CHART



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The development and installation of an Instrumentation Package for GE F404 Investigative Testing is described. The package is used in conjunction with the ARL Mobile (Transient) Data Acquisition System (MODAS) and can be used on the F404 engine at both Fixed or Mobile Engine Test locations - AGAETF or METS. (Australia,

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